DroMOOC

Sensor Fusion and State Estimation

Basic Level

Sensor Technology

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ONERA

Key ideas

Proprioceptive measurements

Internal measurements of the robot motion
Wheel encoders, accelerometers, gyrometers

Exteroceptive measurements (a.k.a Perception)

Relative to the environment or some external reference
Range sensing (Ultrasound, Infrared, Lidar, Radar), barometers, magnetometers, cameras
External systems: triangulation (satellites, beacons), motion capture

Sensor characteristics

- Energy emission: active or passive system
- Physical variable measured
- Acquisition Frequency
- Accuracy (noise, bias, drift), calibration requirements

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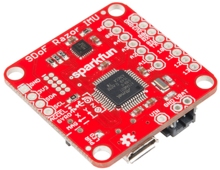
Inertial Measurement Unit

Classical IMU configuration

- 3-axis accelerometers: proper acceleration ("deviation from free fall") in $\mathcal{F}_\mathcal{B}$
- 3-axis gyrometers: angular velocity Ω in $\mathcal{F}_\mathcal{B}$
- 3-axis magnetometers: North direction from Earth's magnetic field
- Barometric altimeter: atmospheric pressure, can be converted into a height measurement



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Characteristics

- For micro-air vehicles: MEMS. Typical frequency: 100 Hz
- Accelerometers suffer from biases and high-frequency noise
- Gyrometers suffer from drift and low-frequency noise
- Magnetometers are sensitive to local magnetic fields
- Barometers are (very) sensitive to weather conditions

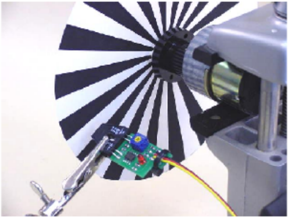
Wheel encoders

Principles

- Coders measure the angular displacement of a robot wheel
- Combining angles of multiple wheels and geometric parameters make it possible to estimate speed and angular velocity in $\mathcal{F}_{\mathcal{B}}$
- Different technologies: optical, electro-mechanical
- Accuracy related to quantization, i.e. angular resolution (1 degree or less)
- Does not take into account sliding or uneven terrain

Vishay Spectrol

Pololu

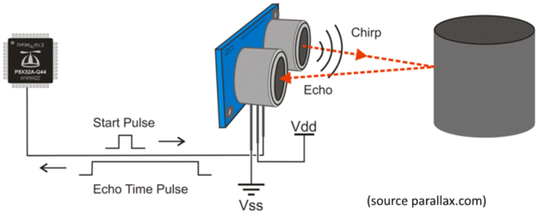


Lynxmotion

Range sensing

Principles

- Ranging sensor, Telemeter, Range Finder. Acquisition frequencies from 20 to 200 Hz.
- Emission of a known wave and measurement of its travel time: distance to obstacle
- Each type of source has its own characteristics
- Pointwise (in a beam) or 3D data, Multipath issues



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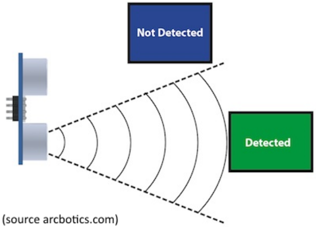

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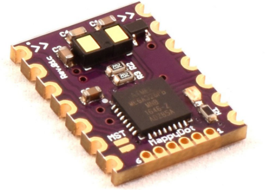
Infrared

Low power, lightweight (a few g), short range (1 to a few meters), Pointwise measurement (small beam), quantization 1 cm



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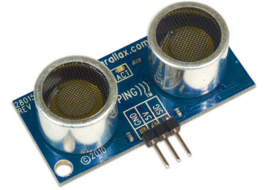
Ultrasonic

Low power, lightweight, higher range (several meters), dead zone (20 cm), low accuracy (a few cm), large beam (10 to 20°)



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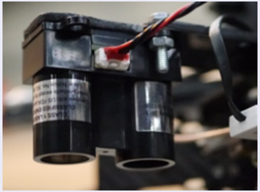
Laser telemeter

Pointwise measurement, high range (40-100 m),
still lightweight (20-30 g), quantization 1 cm



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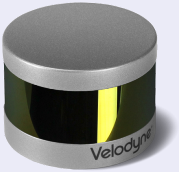
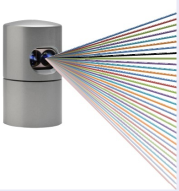
2D/3D Laser scanner (Lidar)

Higher power and weight (300-800 g), high range (30-100 m), large horizontal FOV (270-360°), small vertical FOV (0-15°)



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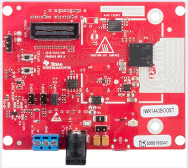
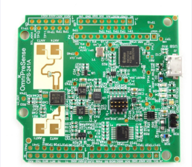
Millimeter-wave radar sensors

Speed measurement or obstacle detection (range 20 m),
wide beam (70-90°), quite robust to weather conditions

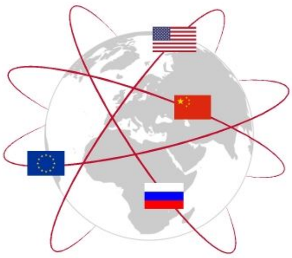


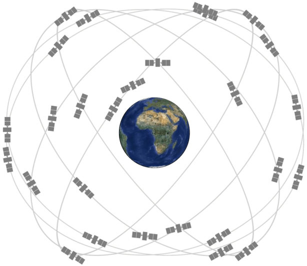


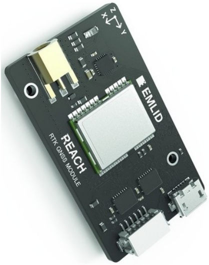
Global Navigation Satellite System

Key principles

Active satellite constellations: GPS, GLONASS, Galileo, Beidou
Broadcast location (monitored from ground stations) and time (synchronized atomic clocks)
Reicever computes its location on Earth by trilateration (only distances involved)
Uncluttered outdoor conditions required. Frequency 1 Hz, raw accuracy 3 to 10 m.
Enhancements (accuracy <1 m) with local relays: Differential GPS (D-GPS or RTK)





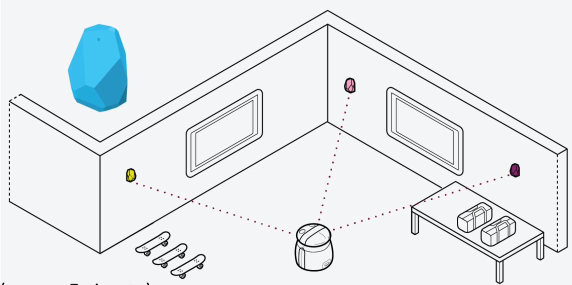


Triangulation / Trilateration (beacons)

Different types

Beacons provide distance measurements to a receiver (and orientation for some of them)
Short communication range (a few meters) implies constraints on coverage and visibility

- Visual or infrared imagery (known patterns)
- Radio communication (Wi-Fi, Ultra-WideBand, Bluetooth)



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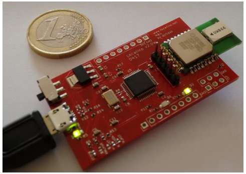
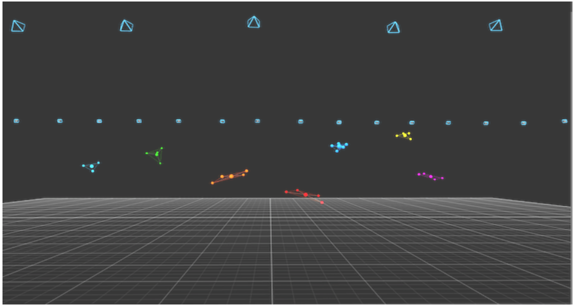
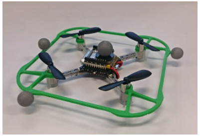


Motion capture systems

Principles

- Active IR cameras with overlapping FOV, calibrated together on a local network
- Several known markers attached to a rigid body are detected and tracked
- Provides position and orientation in laboratory environment
- High frequency (>200 Hz), High accuracy (1 mm), low noise
- Main manufacturers: Vicon, Optitrack





Embedded cameras and depth sensors

Characteristics

2D/3D dense signals with high resolutions. Typical frequency 20 to 100 Hz.
Requires signal and data processing (inside or outside the sensor)

- Monocular vision: CMOS, Fisheye, Event-based
- 3D information from Stereo-vision (see *Computer Vision*) and depth sensors (RGB-D)

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Monocular vision

Successive images of a single camera provide projected information on the robot motion and environment

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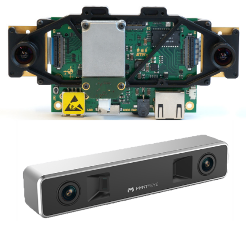
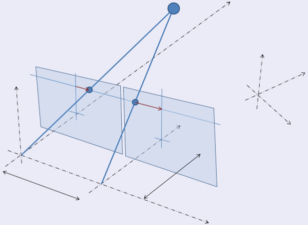
Stereo-vision

Rigid Pair of overlapping calibrated cameras, can localize 3D points in the environment for localization and mapping





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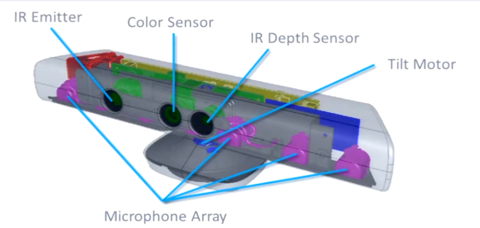
Depth sensors (RGB-D)

Combination of color and IR cameras with projected pattern, directly provides a depth map as additional output



Concluding remarks

Many sensors available for mobile and aerial robots

- Proprioceptive (IMU) and exteroceptive sensors (range sensors, embedded vision)
- External localization systems (GNSS, motion capture)
- Different types and associated characteristics (frequency, quantization, accuracy)
- Importance of environmental conditions (indoor, outdoor, weather, disturbances)
- Quantities of interest for robot navigation (p, v, q, Ω) not measured directly or reliably

What's next?

Techniques for sensor fusion and state estimation